

field in the cell. If the conditions under which the atoms are exposed are those of EIT, then the shift of Zeeman sub-levels of the atoms caused by a change in the magnetic field results in a change in the index of refraction of the region containing the atoms. The change in the index of refraction is measured by means of a Mach-Zehnder optical interferometer. Then the change in the magnetic field can be computed from the known relationship between the magnetic field and the index of refraction.

A photonic crystal is an engineered periodic dielectric structure that can be

tailored by design to exhibit one or more of a rich variety of optical properties. Notable among these properties is a range of photon energies, known as the photonic band gap (PBG), in which light cannot propagate. In an optical EIT magnetometer according to the proposal, sensitivity would be increased by using a photonic crystal to control and enhance the interaction between the resonant atoms and the optical beam. A cloud of the resonant atoms would be embedded in a photonic crystal rather than in a uniform dielectric material in a cell as in a state-of-the-art

optical EIT magnetometer of prior design. The photonic crystal would be designed so that the photon frequency at the edge of the PBG would closely approximate the atomic transition frequency. In the PBG-edge region, the variation of the index of refraction with a change in the magnetic field would be orders of magnitude greater than in the absence of the photonic crystal.

This work was done by Igor Kulikov and Lucia Florescu of Caltech for NASA's Jet Propulsion Laboratory. For further information, contact iaoffice@jpl.nasa.gov. NPO-43802

WGM-Resonator/Tapered-Waveguide White-Light Sensor Optics

Light patterns formed by these optics contain information on absorption spectra.

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Theoretical and experimental investigations have demonstrated the feasibility of compact white-light sensor optics consisting of unitary combinations of (1) low-profile whispering-gallery-mode (WGM) resonators and (2) tapered rod optical waveguides. These sensors are highly wavelength-dispersive and are expected to be especially useful in biochemical applications for measuring absorption spectra of liquids.

These sensor optics exploit the properties of a special class of non-diffracting light beams that are denoted Bessel beams because their amplitudes are proportional to Bessel functions of the radii from their central axes. High-order Bessel beams can have large values of angular momentum. In a sensor optic of this type, a low-profile WGM resonator that supports modes having large angular momenta is used to generate high-order Bessel beams. As used here, "low-profile" signifies that the WGM resonator is an integral part of the rod optical waveguide but has a radius slightly different from that of the adjacent part(s).

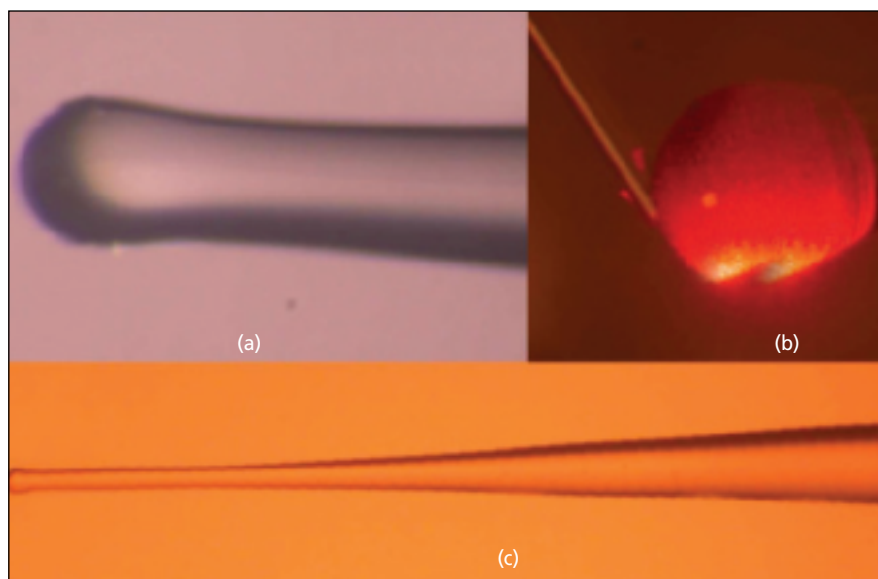
An important difference between such an optic and an ordinary WGM resonator is that its modes decay primarily into Bessel modes of the optical waveguide, rather than to the outside. By changing the dimensions and shape of the WGM resonator and/or the radius of the adjacent part(s) of waveguide, it is possible to change the resonator loading and thereby tailor the degree to which

light propagates from the resonator along the waveguide.

The feasibility of applications that involve exploitation of optical waves that have angular momentum depends on the propagation distances of such waves in free space. A high-order Bessel beam that propagates from a WGM resonator along a cylindrical waveguide with evanescent-field coupling cannot leave the waveguide; it propagates to an end of the waveguide, where it is totally internally reflected back along the waveguide toward the other end. However, if

the waveguide is tapered, as in an optic of the present type, then the optic acts as radiator horn that preserves the angular momentum of the axially propagating Bessel beams while changing their axial momentum. A notable result of propagation along the taper is that upon reaching the wide end, the Bessel beams can be released into the space outside the waveguide and their shapes are preserved.

An optic of the present type can be made by cutting and polishing a bump/dip toroidal pattern on the side



An **Experimental Optic** of the type described in the text is a unitary structure consisting of a WGM resonator on the narrow end of a tapered fused-silica rod: (a) WGM resonator, (b) coupling light into the WGMs of the resonator using cleaved fiber, and (c) tapered fiber used to release generated Bessel beam into free space.

of a rod of transparent material or partly melting the tip of the rod. For example, the figure depicts such an optic made from a fused-silica rod of 30-mm length that tapers from 0.45-mm diameter at the narrow end to 3 mm at the wide end. The WGM resonator is a 500- μm axisymmetric bulge at the narrow end, formed by using a hydrogen torch to partly melt the narrow end. In operation, light is coupled into the WGM

resonator via the cleaved tip of an optical fiber.

In use of such an optic as a sensor, the rod is dipped into liquid, the absorption spectrum of which one seeks to measure. Interference among the Bessel beams in the far-field region of the waveguide forms a helix-shaped light field. A charge-coupled-device camera is installed at a distance between 2 and 30 mm from the wide end of the optical fiber to observe

this field. The dependence of the brightness of this field on the azimuth angle contains information on absorption as a function of wavelength.

This work was done by Dmitry Strehalov, Lute Maleki, Andrey Matsko, Anatoliy Savchenkov, and Vladimir Ilchenko of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-43363

Raman-Suppressing Coupling for Optical Parametric Oscillator

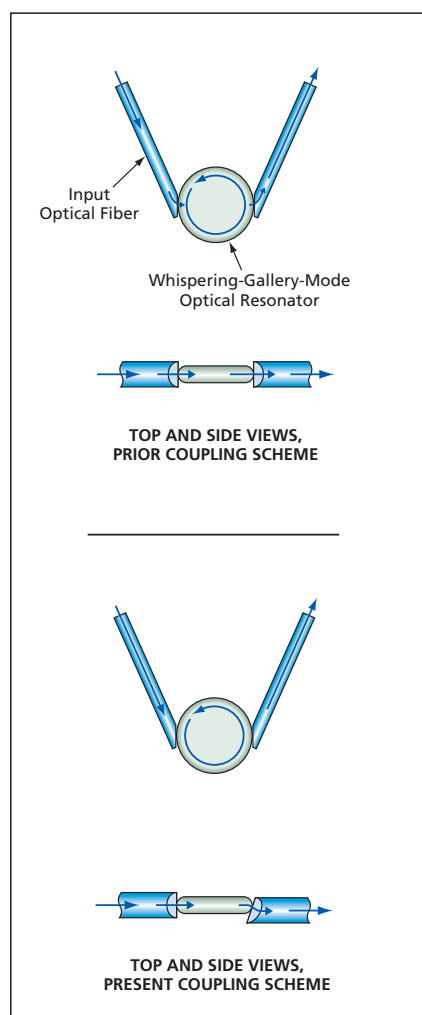
Loading of desired modes is reduced, relative to loading of undesired modes.

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A Raman-scattering-suppressing input/output coupling scheme has been devised for a whispering-gallery-mode optical resonator that is used as a four-wave-mixing device to effect an all-optical parametric oscillator. Raman scattering is undesired in such a device because (1) it is a nonlinear process that competes with the desired nonlinear four-wave conversion process involved in optical parametric oscillation and (2) as such, it reduces the power of the desired oscillation and contributes to output noise.

An all-optical parametric oscillator potentially offers the advantages of a narrow output spectral peak with a low overall noise floor. Often, undesirably, the threshold power for Raman scattering is lower than that for optical parametric oscillation, partly because phase matching is not a necessary precondition for Raman scattering. On the other hand, phase matching is necessary for four-wave mixing, in which pump power in fundamental modes of the resonator is converted to only fundamental modes of a different frequency. Some of the pump laser power needed for optical parametric oscillation can be Raman-scattered to non-fundamental modes of the resonator. The resonance quality factors (Q values) of these non-fundamental modes are not reduced by the presence of input and output fiber-optic couplers designed according to a prior coupling scheme, and the threshold power levels of both competing nonlinear processes decrease with increasing Q values. Moreover, when the pump power reaches the Raman-scattering threshold, the Q values of the pump modes decrease, with consequent increase in the oscillator output noise. For these reasons, it is

highly desirable to utilize a modified coupling scheme to suppress the Raman modes without significantly suppressing the fundamental modes.



These Two Input/Output Coupling Schemes differ in the position and orientation of the output optical fiber. In the present scheme, the output fiber is tilted to reduce coupling to the fundamental modes of the resonator.

The essence of the present input/output coupling scheme is to reduce output loading of the desired resonator modes while increasing output loading of the undesired ones. The figure illustrates the prior and present coupling schemes. In the prior scheme, the input and output couplers are both positioned and oriented to effect coupling to the fundamental modes of the resonator. The Q of the fundamental modes is reduced by this coupling — especially by output coupling to the load. In the present scheme, the input coupler is still positioned and oriented to effect coupling to the fundamental modes, but the output coupler is tilted to greatly reduce coupling to the fundamental modes without reducing coupling to the Raman modes. As a result, the Q values of the fundamental modes are increased while the output loading reduces the Q values (and thereby increases the threshold power) of the Raman modes.

This work was done by Anatoliy Savchenkov, Lute Maleki, Andrey Matsko, and Enrico Rubiola of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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